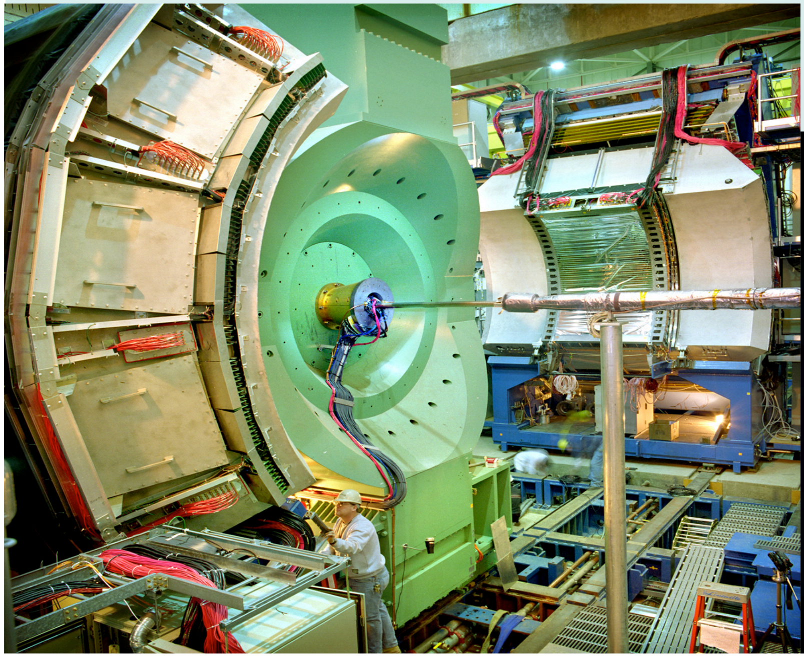
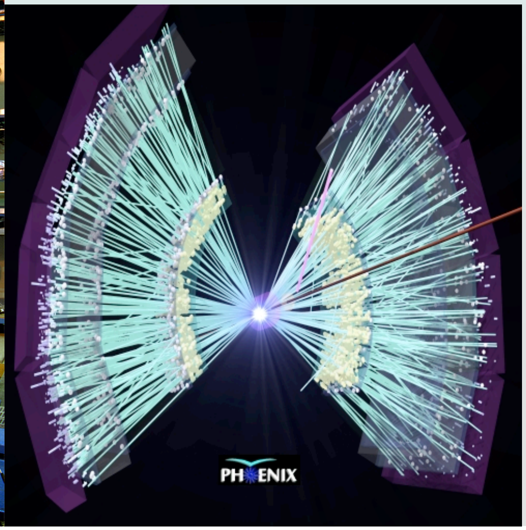
Comparing viscous hydro & data: what's needed to make progress?

The PHENIX view

Barbara Jacak

Dec. 15, 2009





outline

- Goals and issues
- Many hydro models - this is good

  But also bad, benchmarking each one = work
- Two complementary approaches - different goals

  Simpler models to study sensitivities

  Full simulation with all issues addressed
- Observables PHENIX would like to see you study

  Constituent quark scaling at low/moderate p_T

  The break from constituent quark scaling

  Identified hadron flow & hadron gas effects

  Initial condition vs η/s - data to help disentangle

  v_4

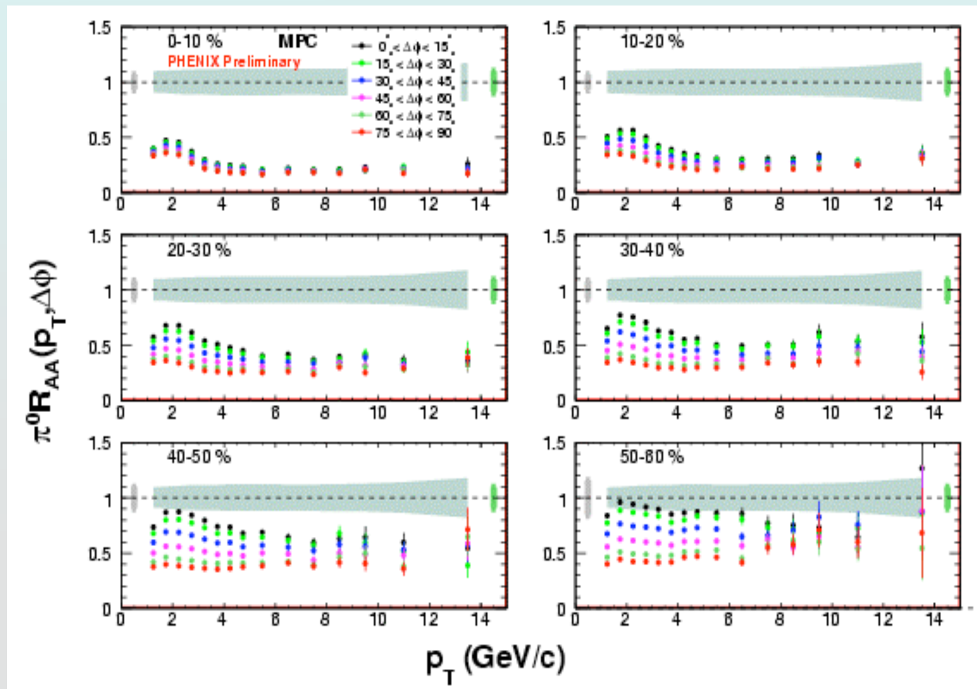
  heavy quark, direct photon flow

What we want to learn

Properties of the quark soup!

- **What is the value of η/s?**
- **What is the initial condition?**
  Glauber, CGC or something else?
- **At high p_{T}:**

precision v_2 measurements probe interplay between medium flow & opacity



Issues*

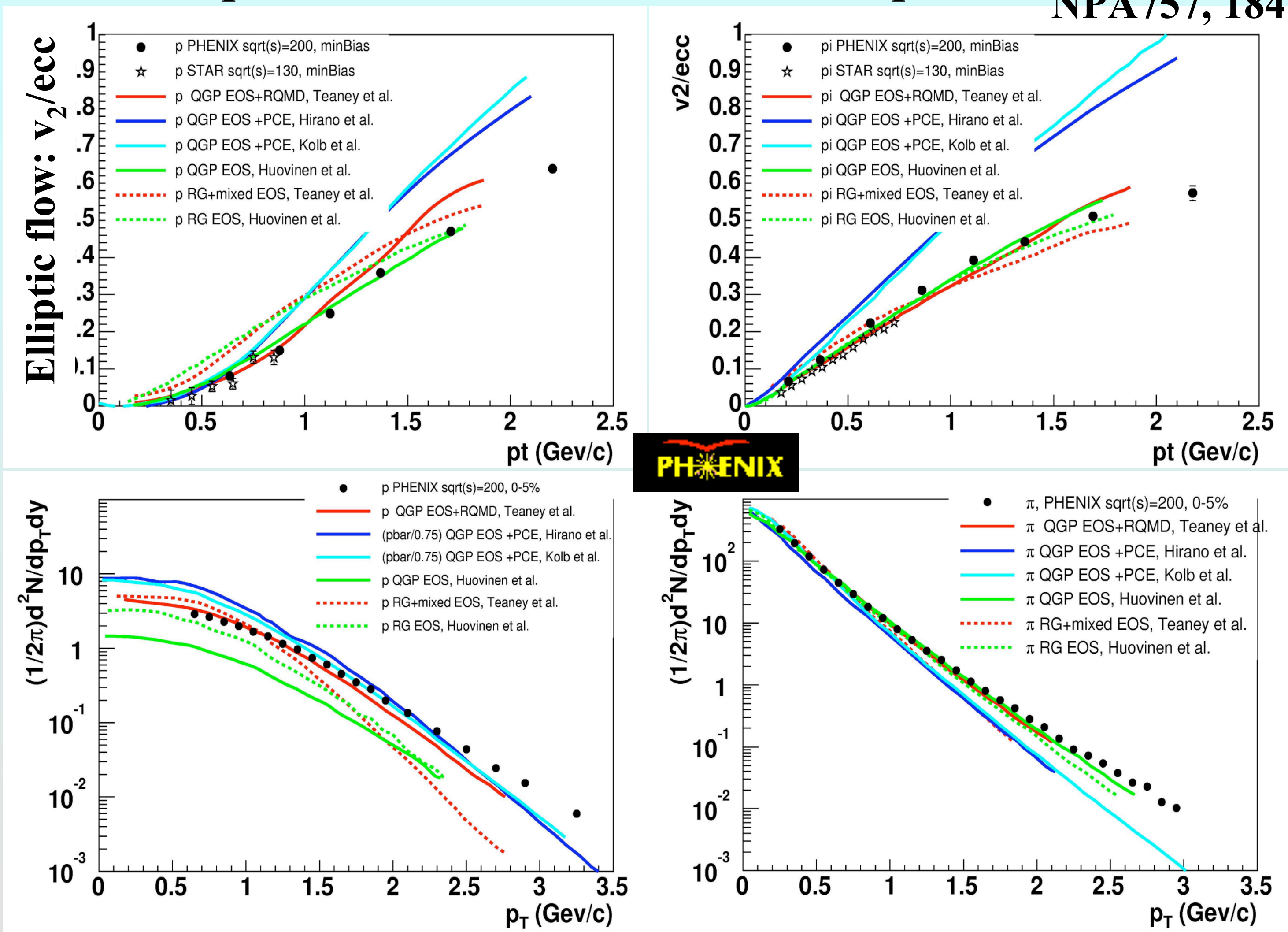
- Hadronic state effects
  Change particle mix, spectra
  Viscous corrections
- Eccentricity fluctuations
- T dependence of η/s
- Non-equilibrium effects
- Bulk viscosity (not small near T_c)

* Discussed extensively on Monday

Important: benchmark your hydro!

proton pion

NPA757, 184 (2005)



Hydro models:

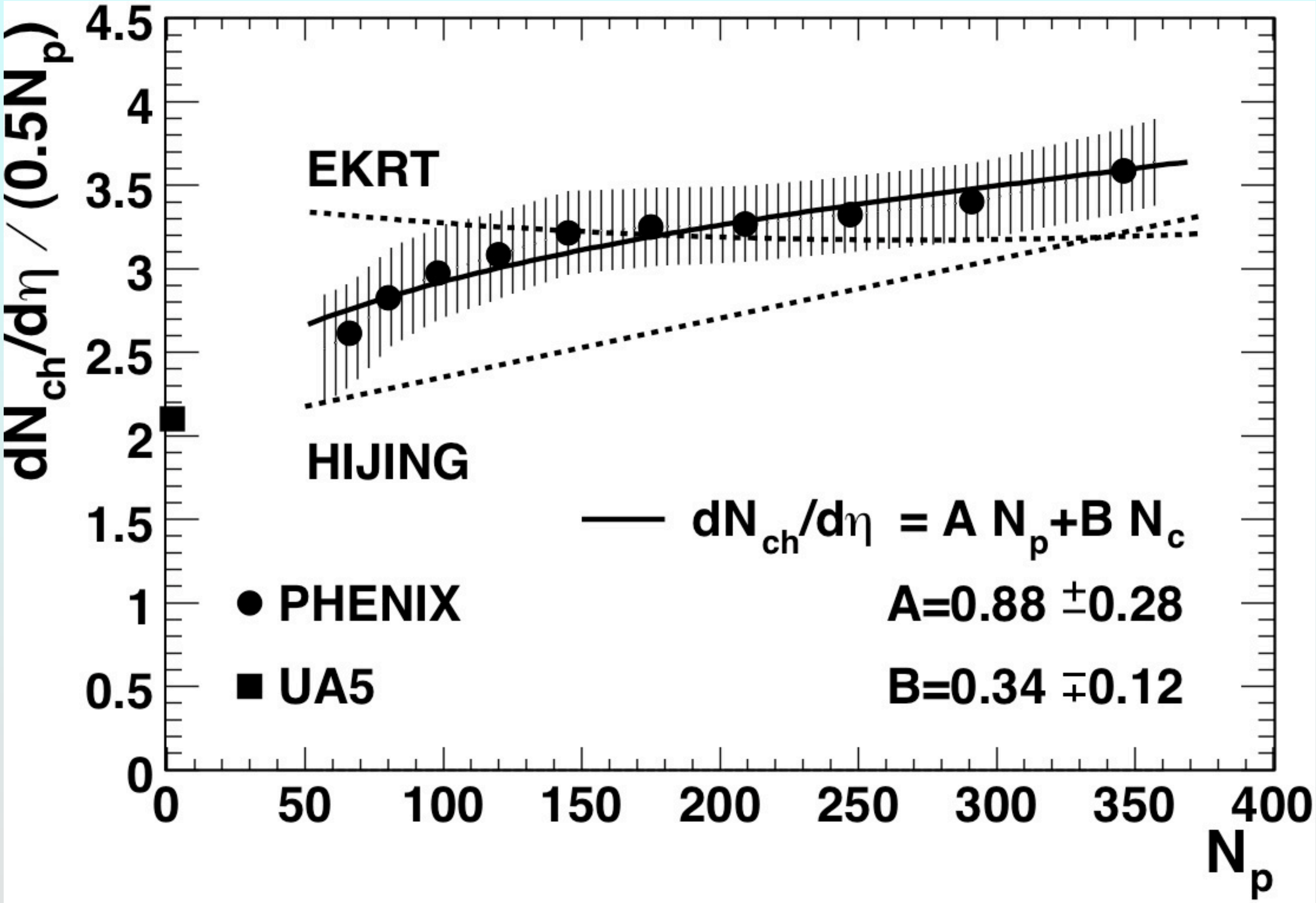
Teaney
(w/ & w/o RQMD)

Hirano
(3d)

Kolb

Huovinen
(w/& w/o QGP)

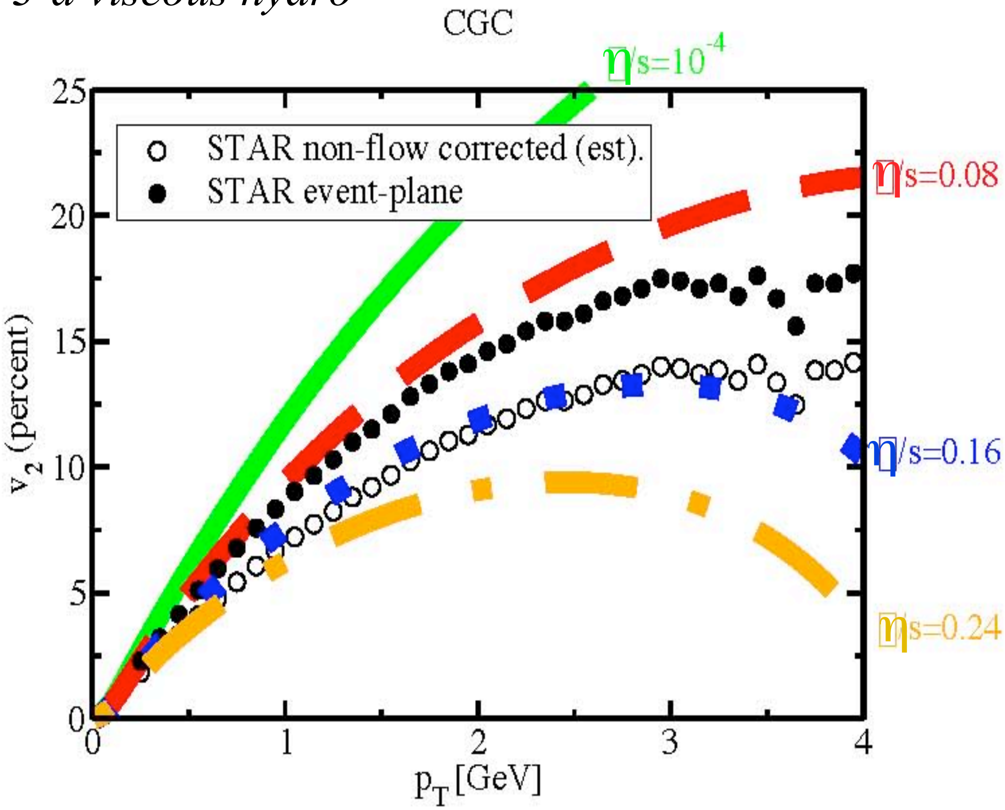
Also via $dN_{ch}/d\eta$



PRL 86 3500 (2001)

Using hydro to pin down viscosity

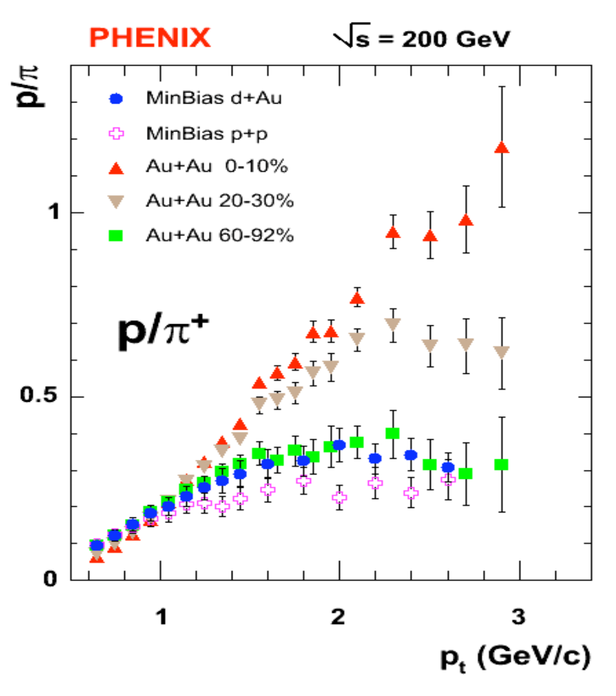
Luzum & Romatschke, PRC78, 034915 (2008)
3-d viscous hydro



There is a problem!

This compares $h^{\pm}$ flow mixing π,K,p together

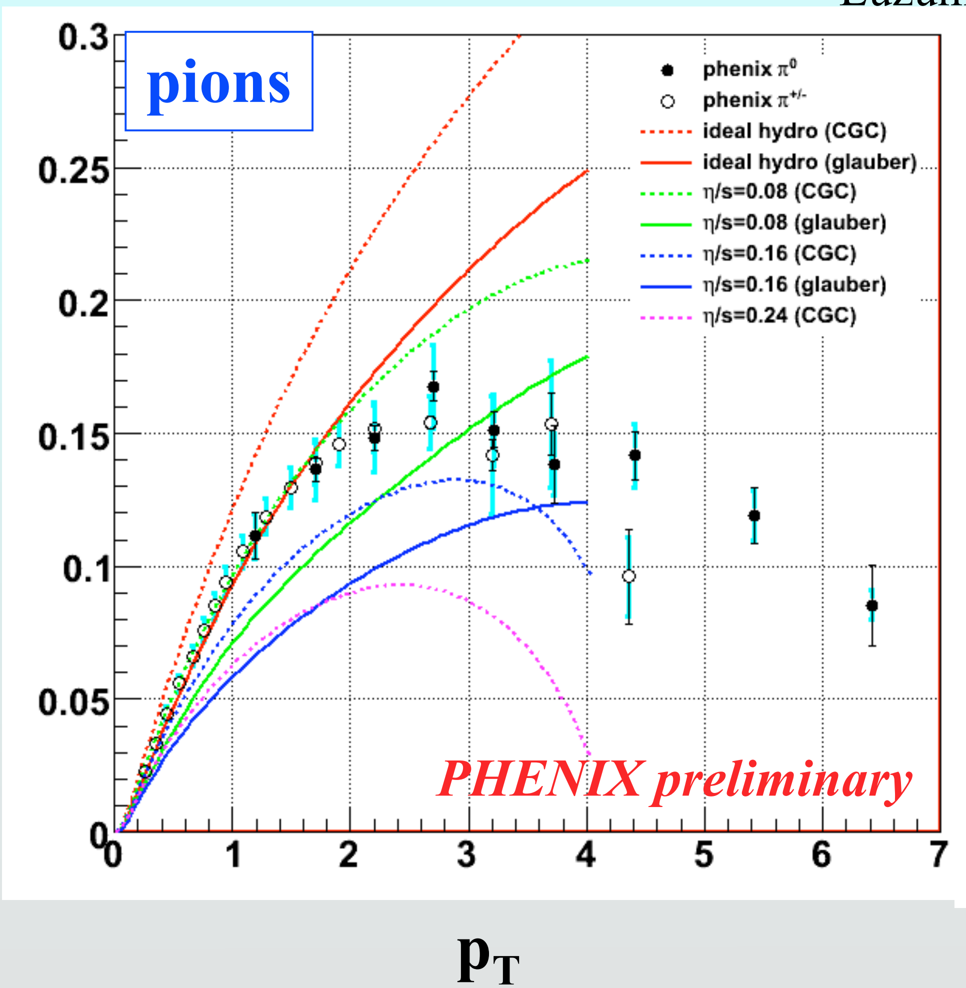
Data: particle mix NOT same as at T_{chem}

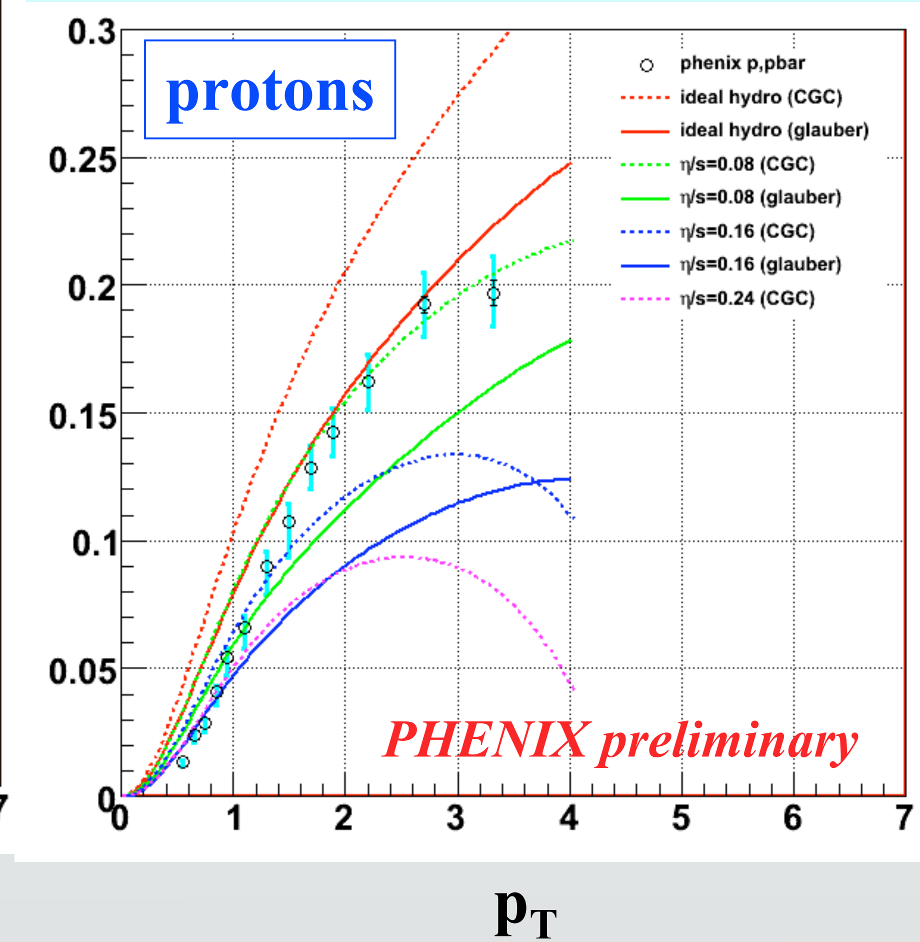


$h^{\pm}$ particle mix calculated at $T_{chemical\ freezeout}$

To do better: pions, protons separately

Romatschke & Romatschke, PRL99, 172301 (2007)
Luzum & Romatschke, PRC78, 034915 (2008)

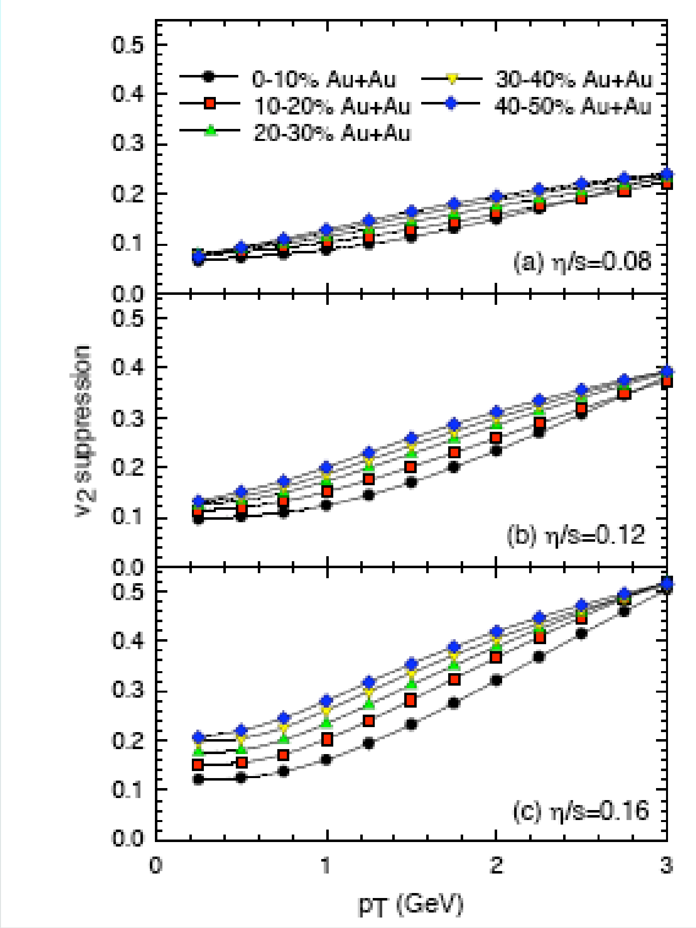


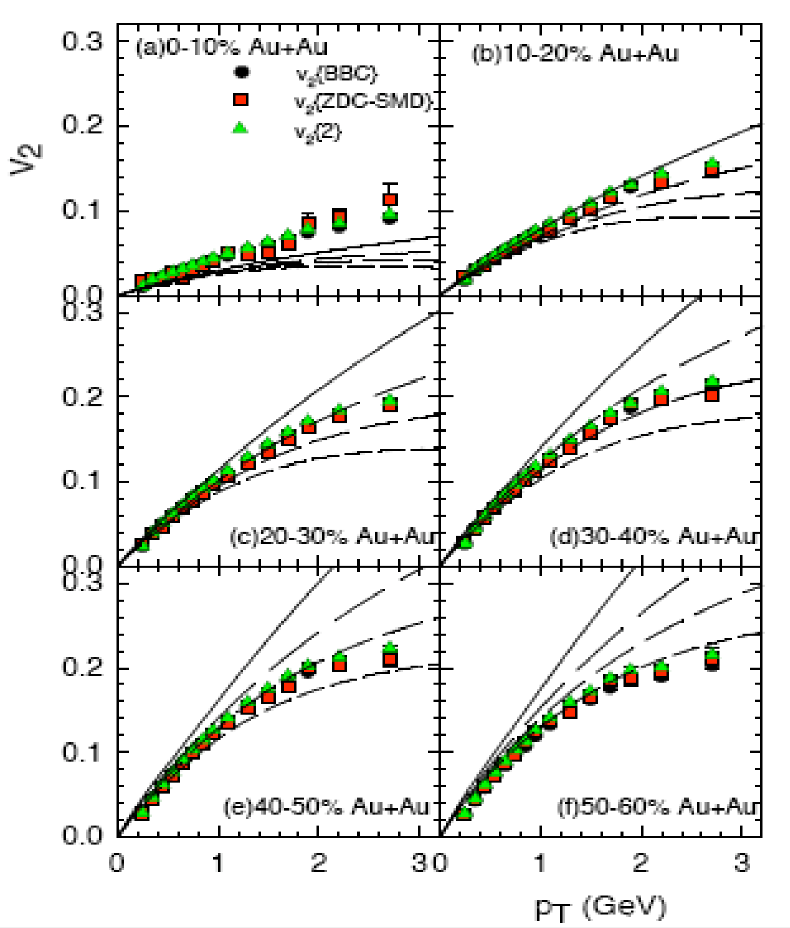


Note that ALL comparisons point to small $\eta/s \leq 0.08$
Need hadron afterburner & initial state control to truly quantify…

2 approaches - useful but different

- **Simple(r): Some/many issues not controlled**





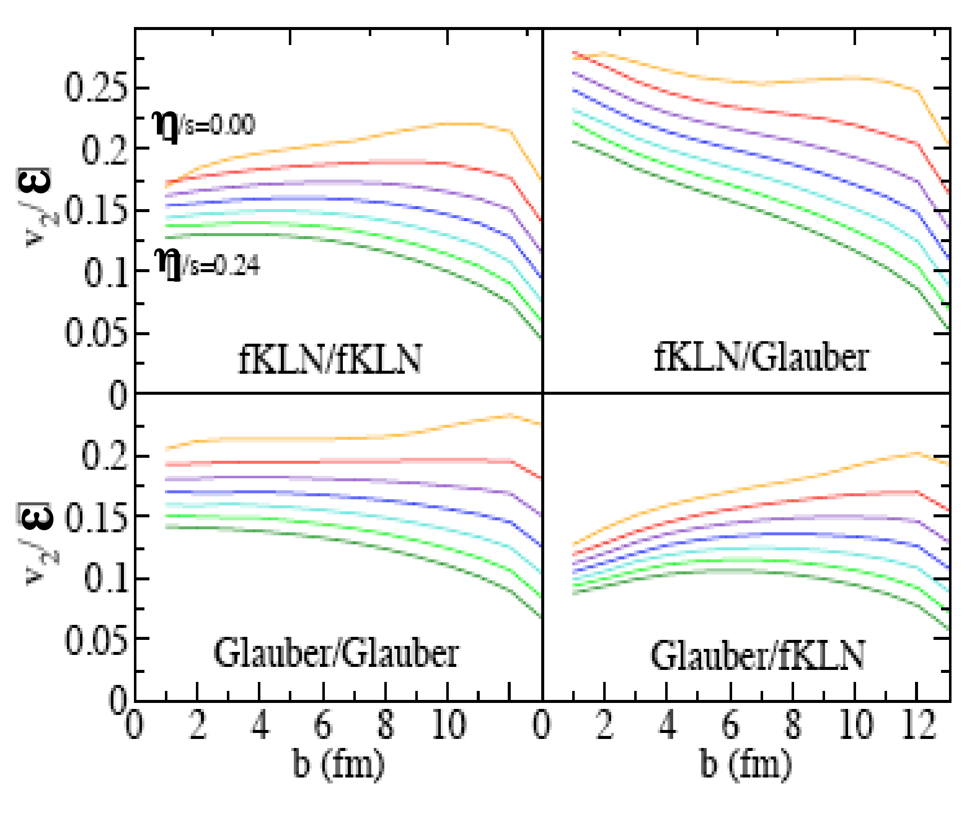
Chaudhuri
0910.0979

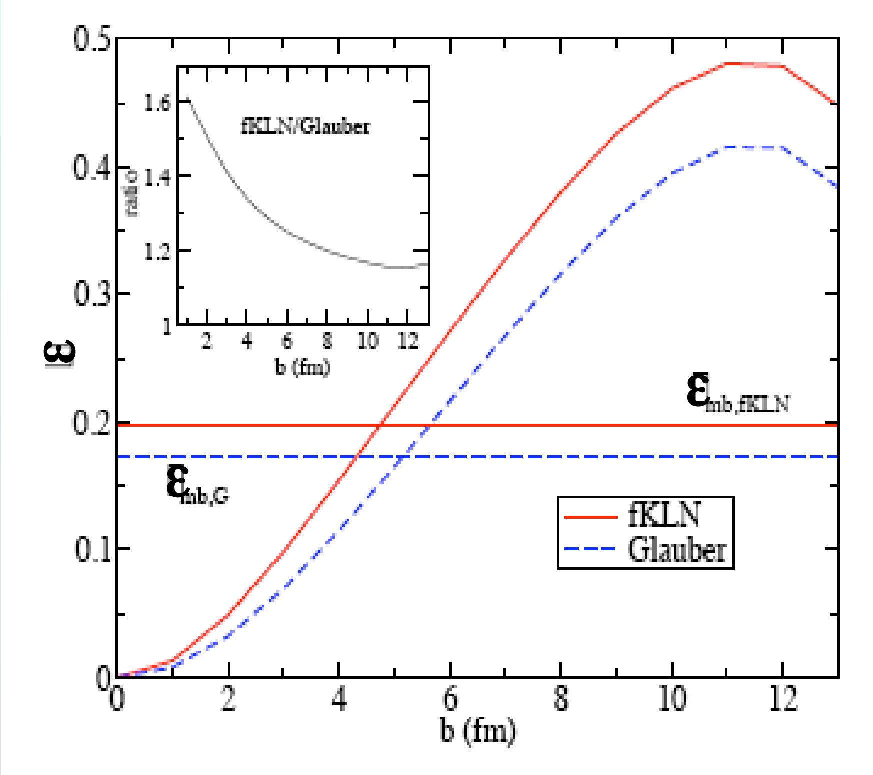
- ***Qualitative* insights on p_T dependence of v_2 suppression & hadron gas effects vs. centrality**
- ***For quantitative:* fluctuations, non-equilibrium effects**

Study of initial conditions

- Centrality dependence of v_2/ε

Heinz, Moreland & Song 0908.2617





- Fluctuations (should be) important in central collisions

  Please include & see if sensitivity persists!

Qualitative vs. quantitative

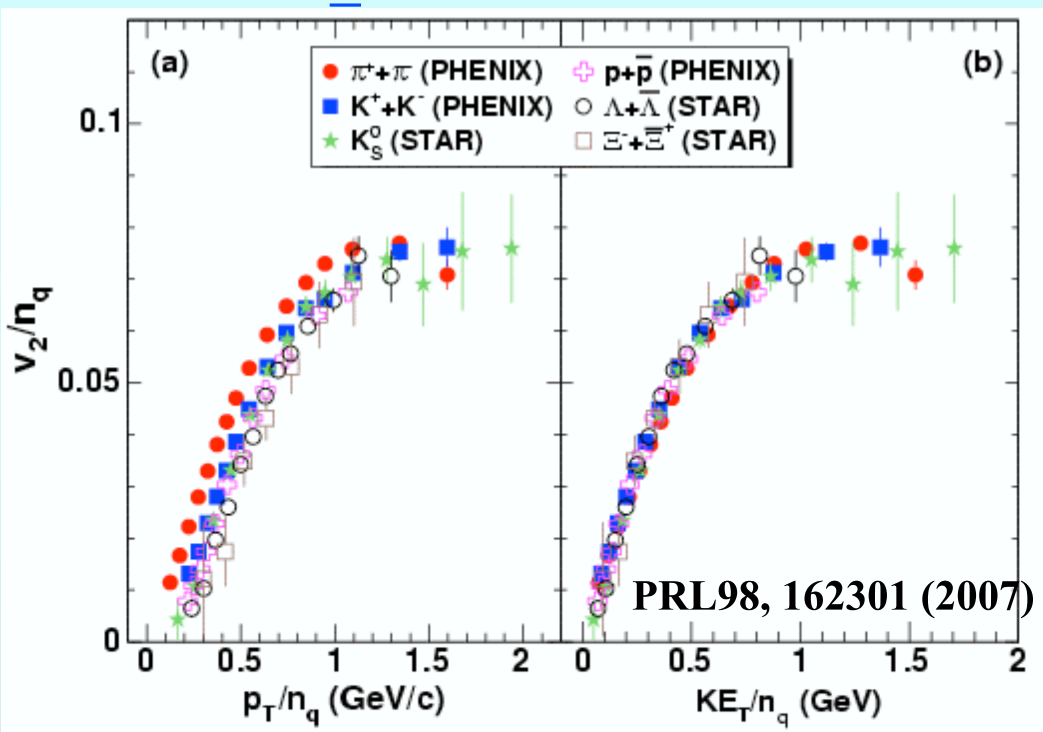
- *Qualitative* studies are very useful
  - Teach us a lot in the short run
  - But we (all) need to be careful to avoid treating these as quantitative results
  - Plea: please note explicitly what is left out
    - state sensitivity of conclusion
- Textbook worthy results will ultimately come from from the “full monty”

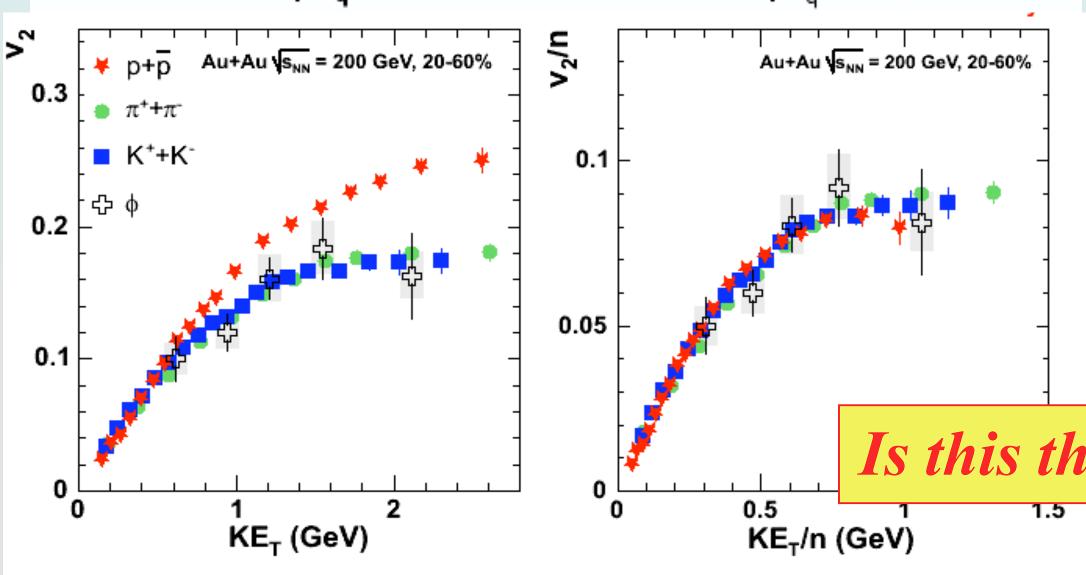
Some of our favorite observables

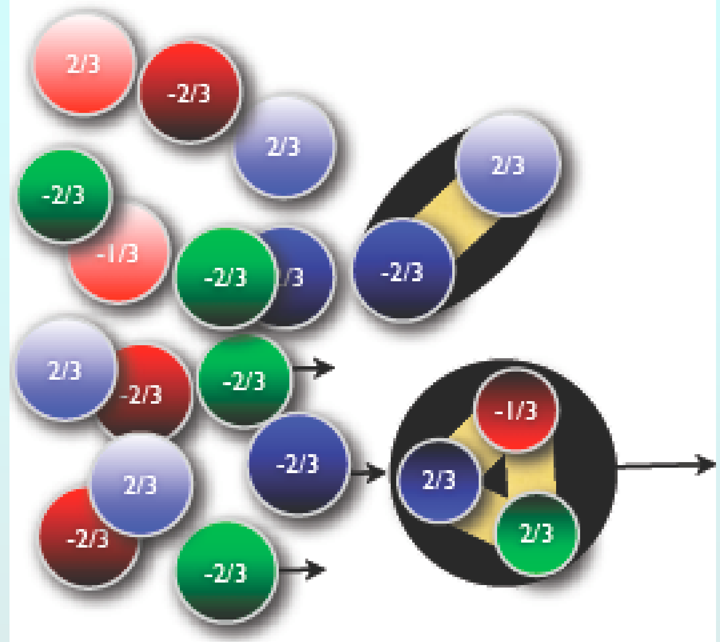
- **Plea to theory:**
  Please calculate these
  Help us draw physics conclusions

- **Comparing data to multiple viscous hydro calculations will push us toward *quantitative* (instead of *qualitative*) physics conclusions**

v_2 scaling with quark number



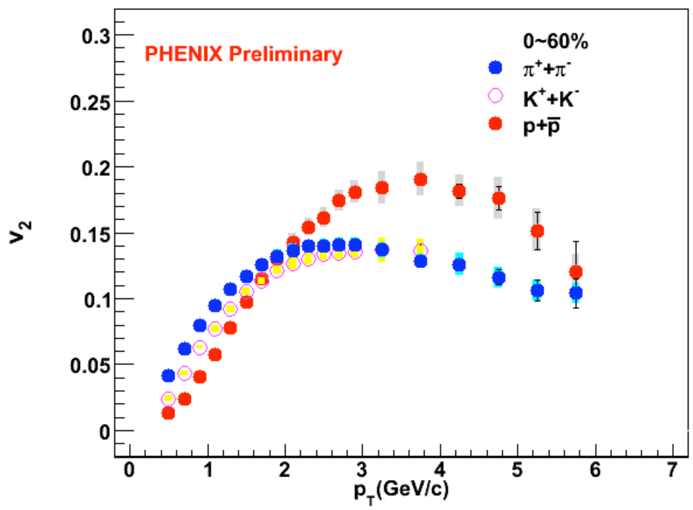


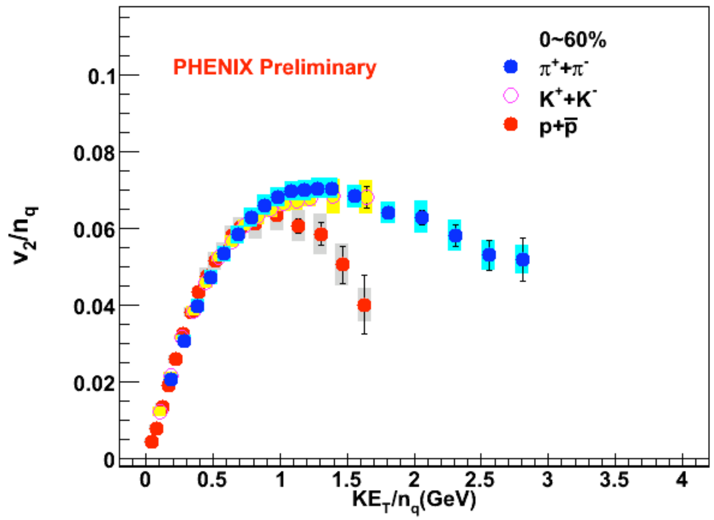


All particles flow
as if frozen out from
a flowing soup of
constituent quarks

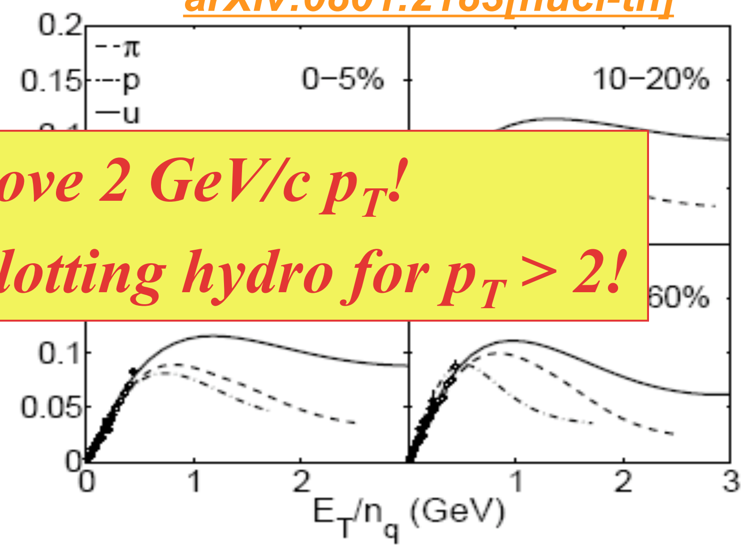
Is this the correct interpretation?

A known known – Scaling breaks at high p_T





Hwa &Yang
arXiv:0801.2183[nucl-th]



- *NCQ scaling is expected to break at*

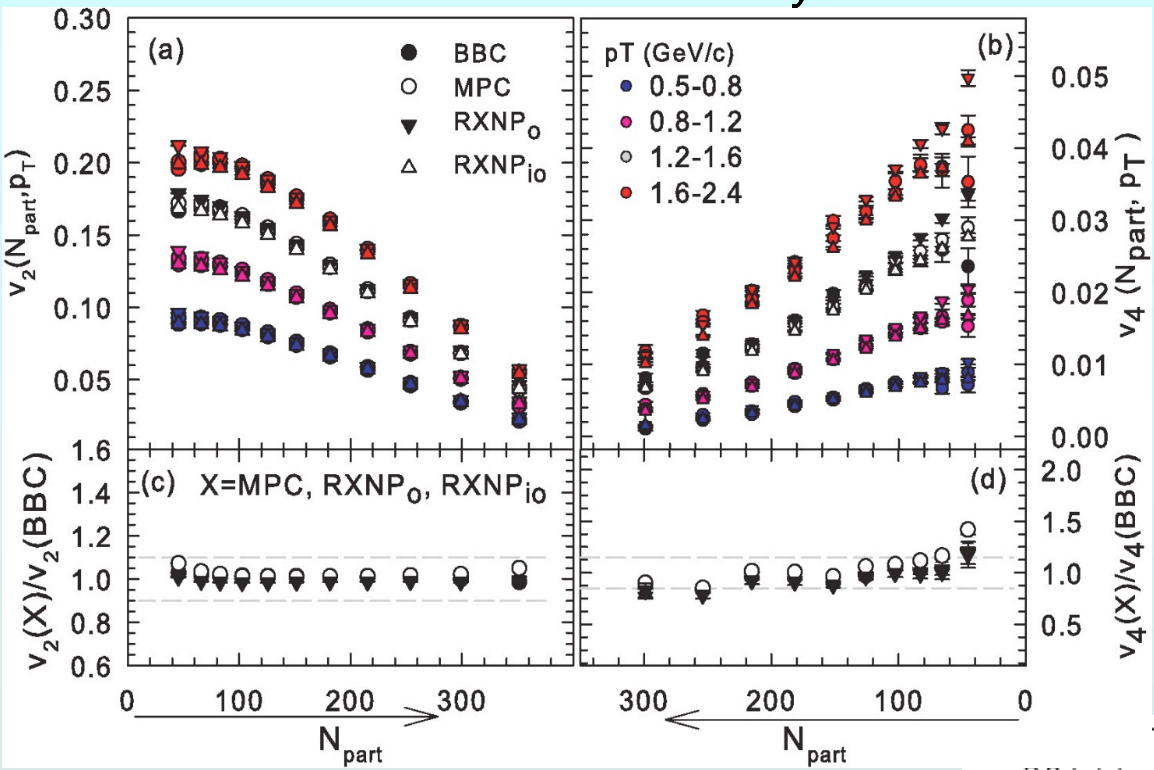
are mainly from TTS and TSS .

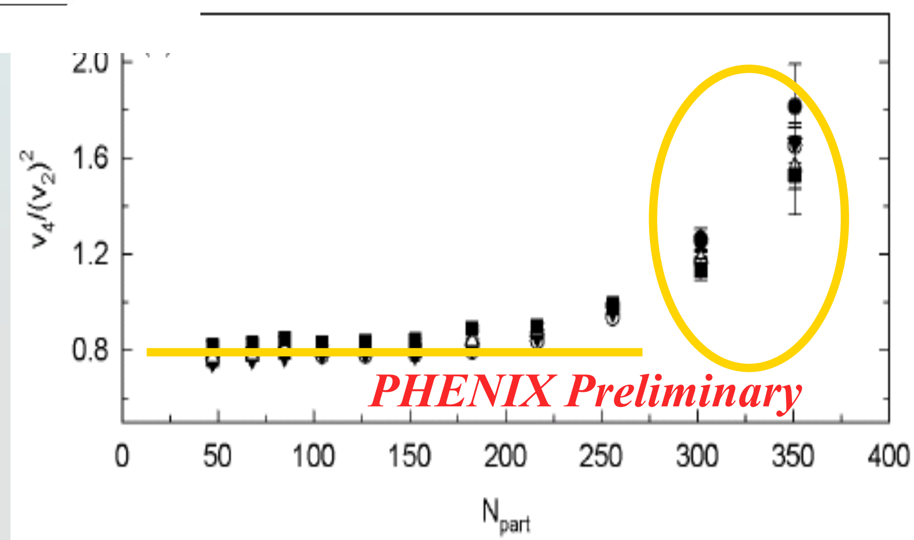
Implies hydro is inapplicable above 2 GeV/c p_T!

Is that agreed? If so, let's stop plotting hydro for $p_T > 2$!

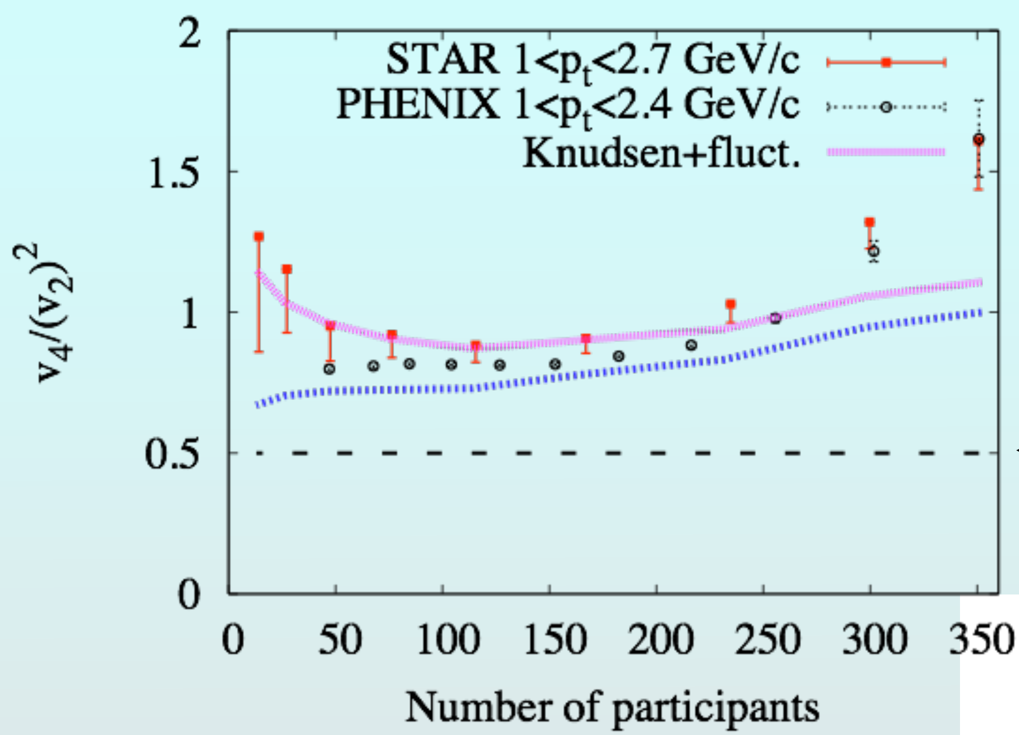
Please calculate v_4!

PHENIX Preliminary





Quantify fluctuations, deviation from equilibrium



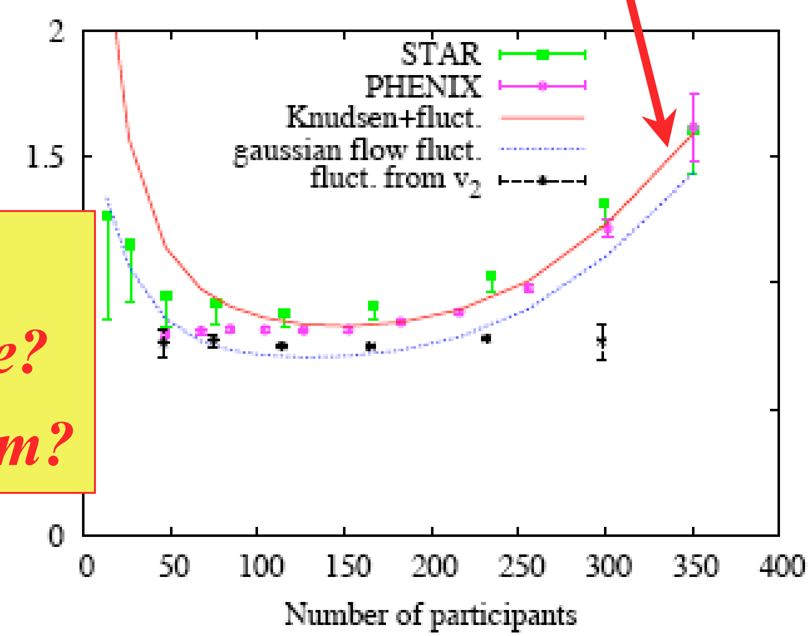
C. Gombeaud, J.-Y. Ollitrault
arXiv:0907.4664, arXiv:0910.0392

Ideal hydro. + fluctuation
+ incomplete thermalization

Ideal hydro. + fluctuation

Ideal hydro.

Gaussian fluctu.
$\propto N_{part}^{-1/2}$
(unknown source)

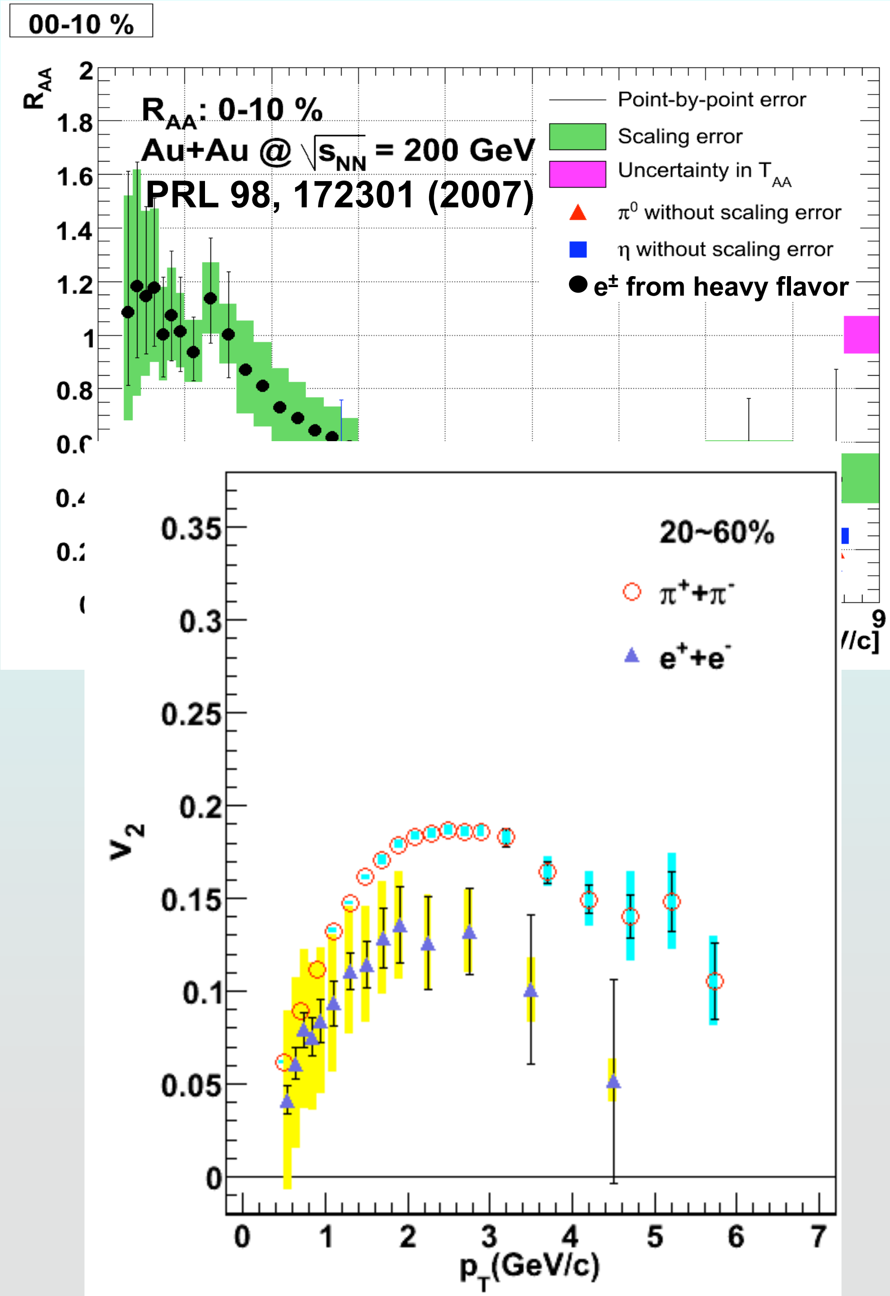


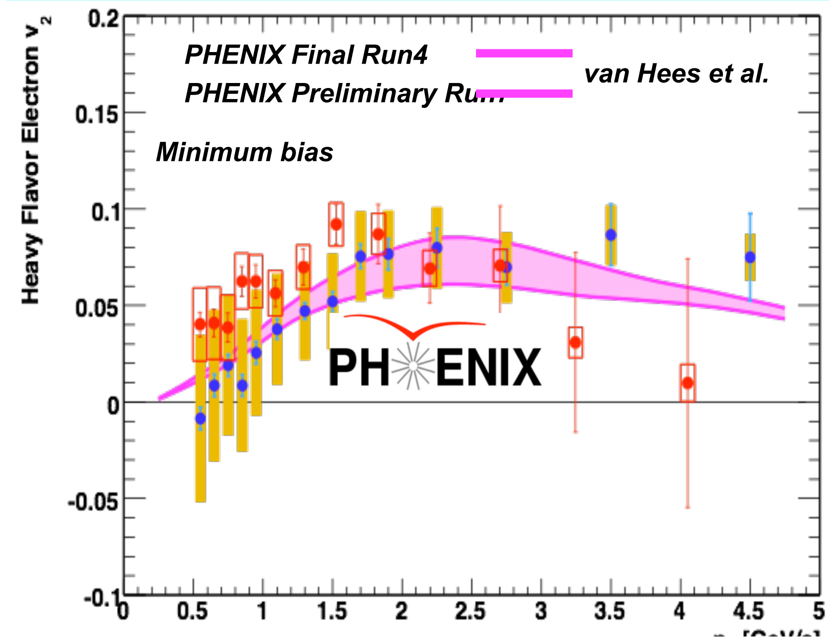
Does everyone else agree?

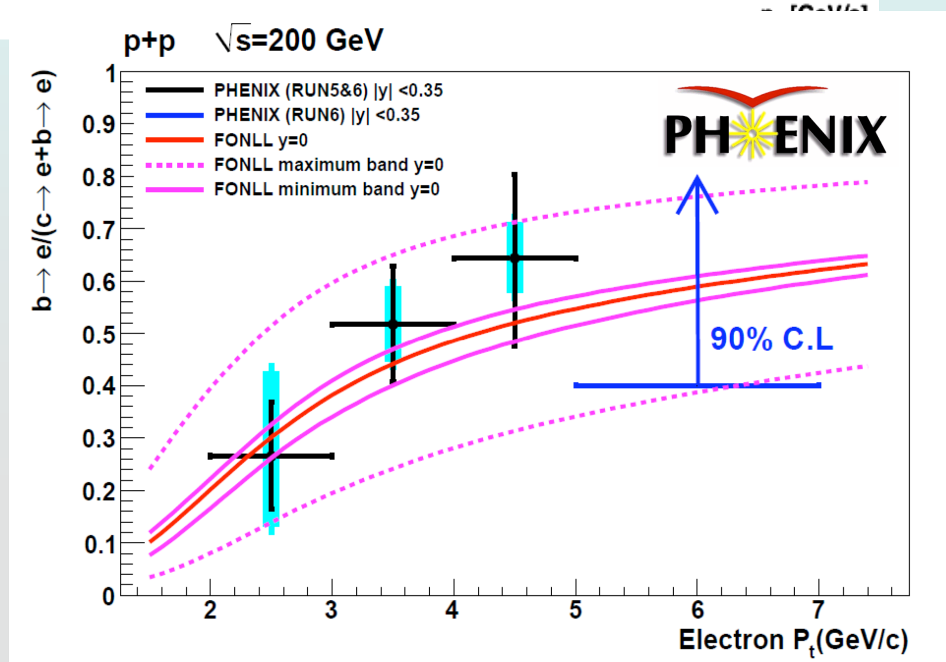
Is impact of fluctuations really so large?

Can we trust anything that ignores them?

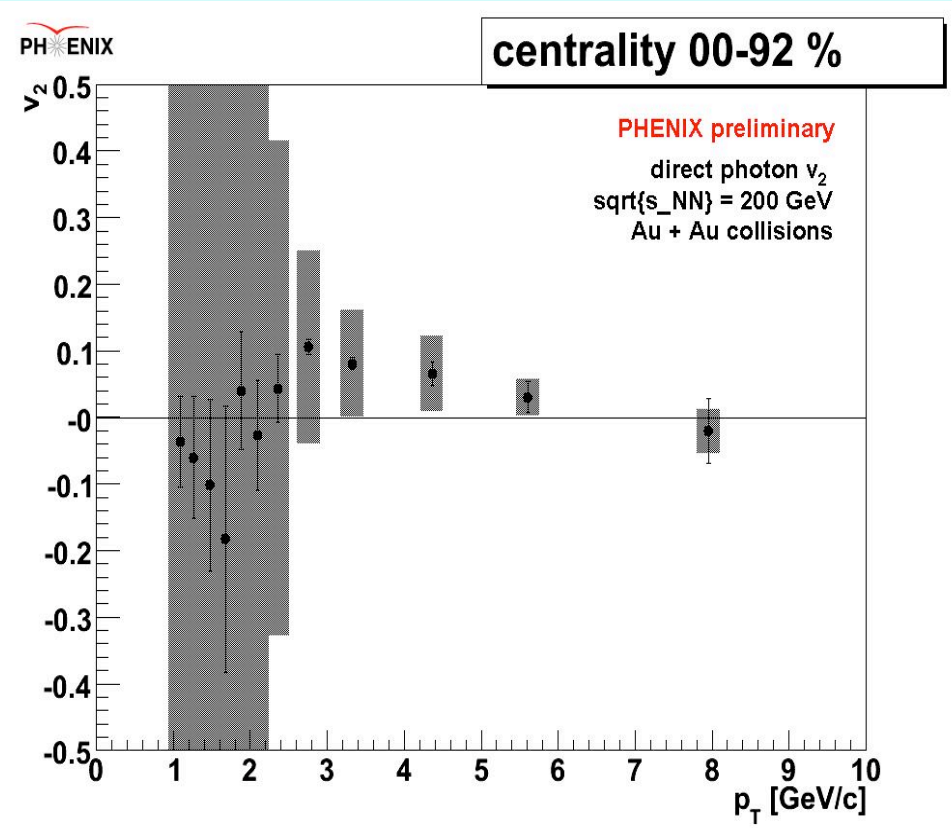
Please look at heavy quark flow!



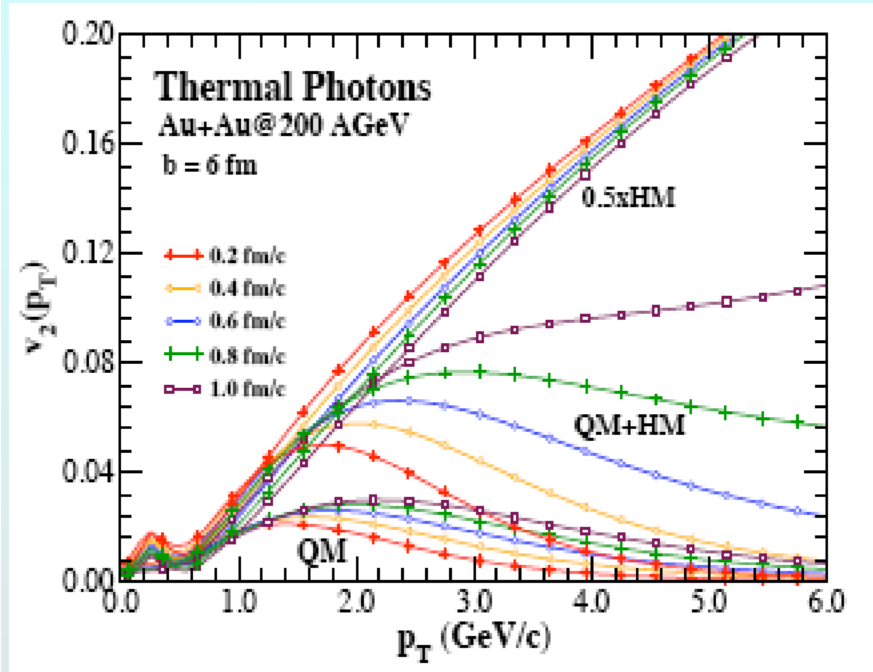




And direct photon flow!



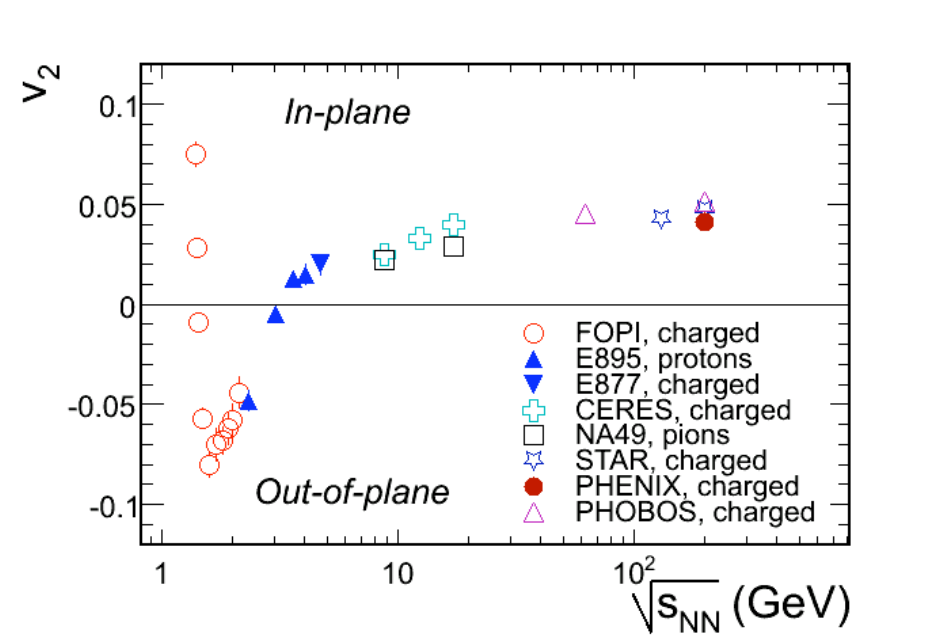
Chatterjee & Srivastava 0908.3548

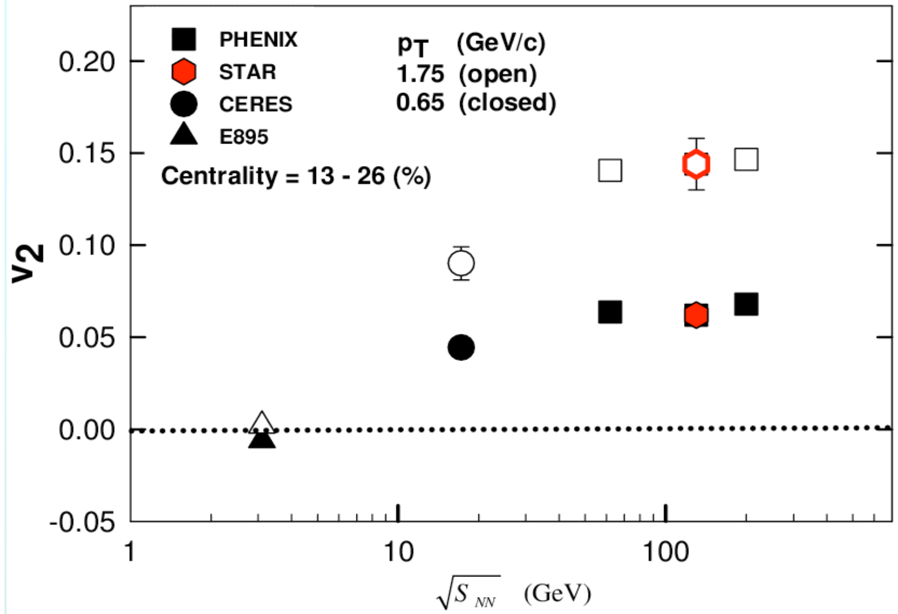


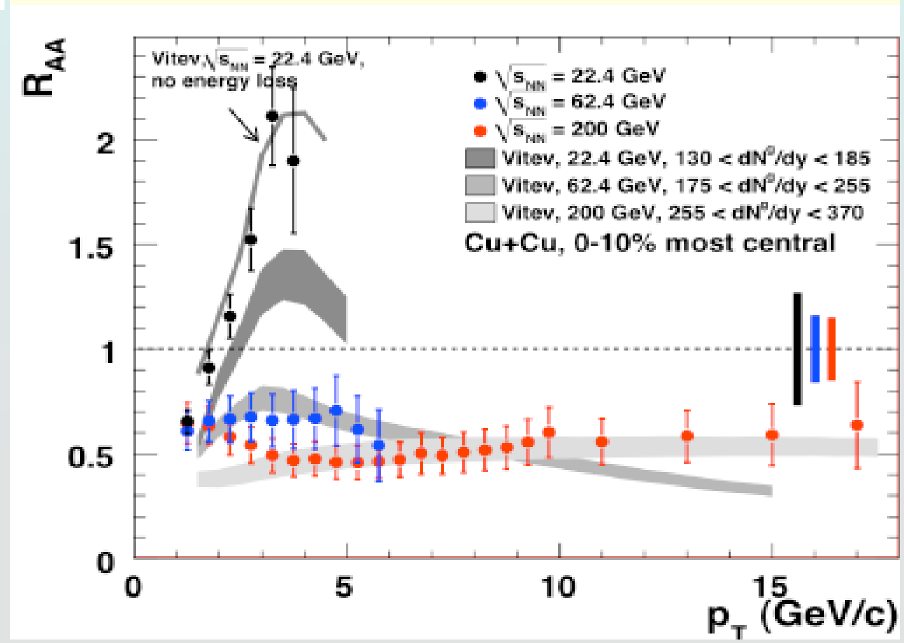
- Photon emission dominated by highest T
  - → Sensitivity to thermalization time

  Do viscous effects mess this up?
- You calculate and we'll measure!

Where/why does v_2 saturate?







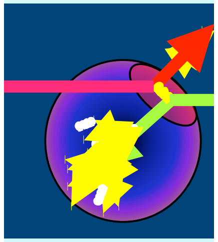
- Why does v_2 saturate?
  - → Minimum η/s??
  - → Signal of QGP onset?
- Where does v_2 saturate?
- You calculate and we'll measure!

Conclusions

- Systematic control of issues is key in long term
  - But can learn a lot from simpler studies in the interim
- Detailed comparison to data as function of PID, p_T, centrality, etc is necessary
  - Represents a lot of work
- We experimenters should *and can and will* help!
  - Maybe create a database of comparison data?

- Backup

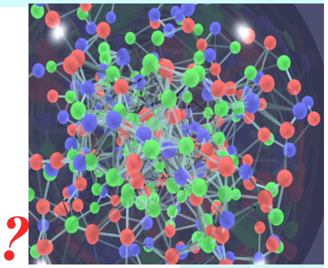
Quark gluon plasma is liquid! *How does it work?*

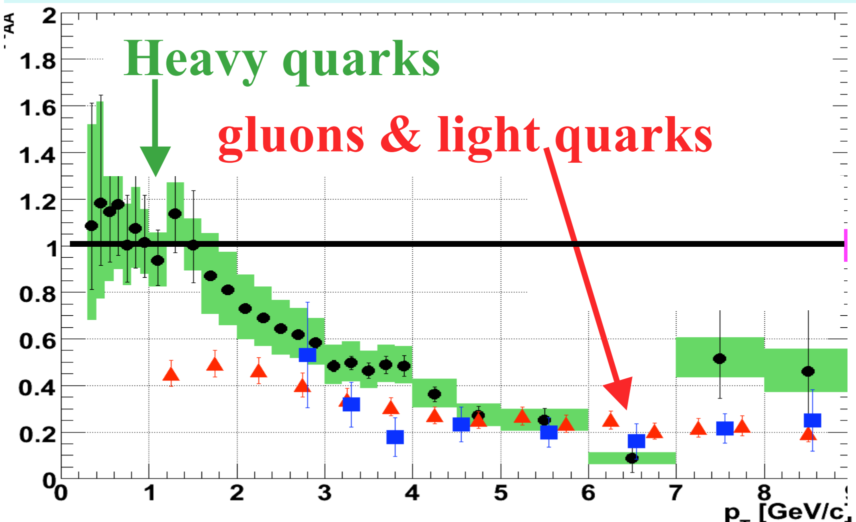


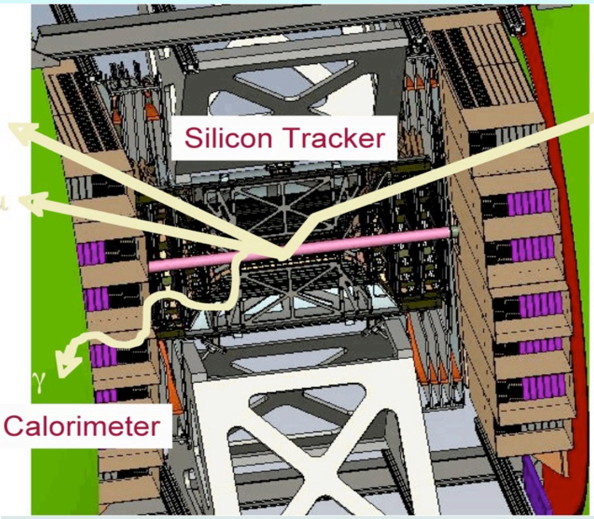
Plasma opaque to light *and* heavy charm quarks

Strongly coupled: neighbors "talk" to each other

To learn: Do b quarks stop too? How does it radiate?

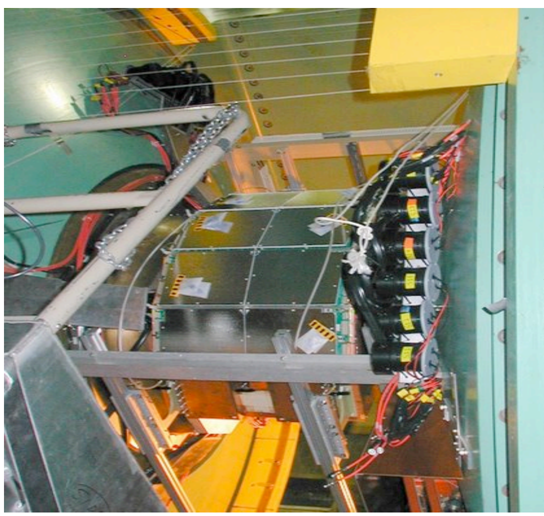






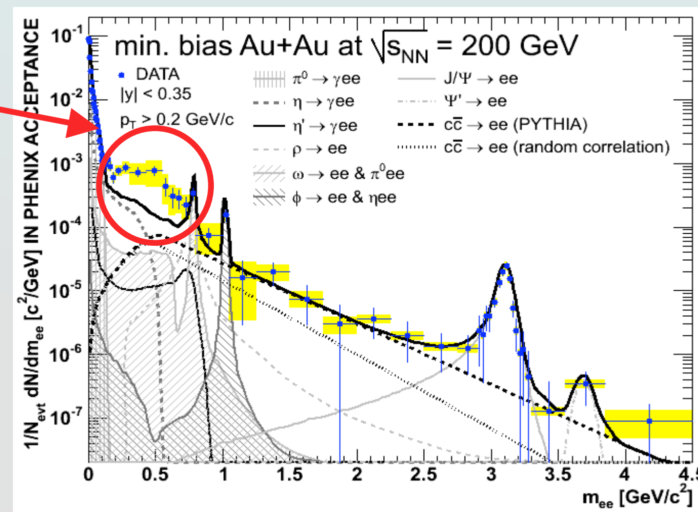
Upgrade:

Si strip/pixel vertex detector to tag $e^{\pm}$ from B decays (2011)

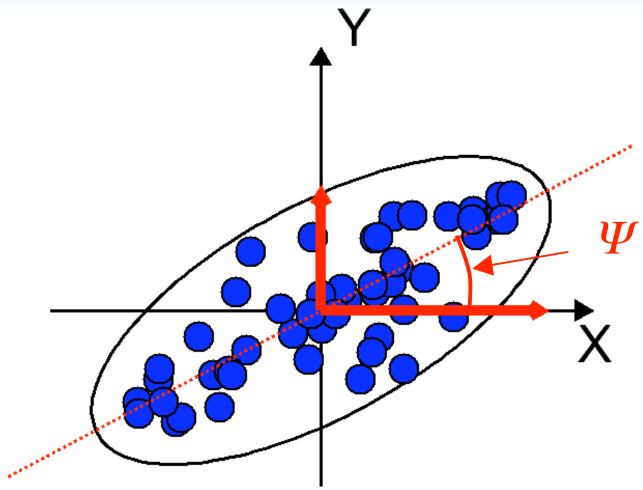


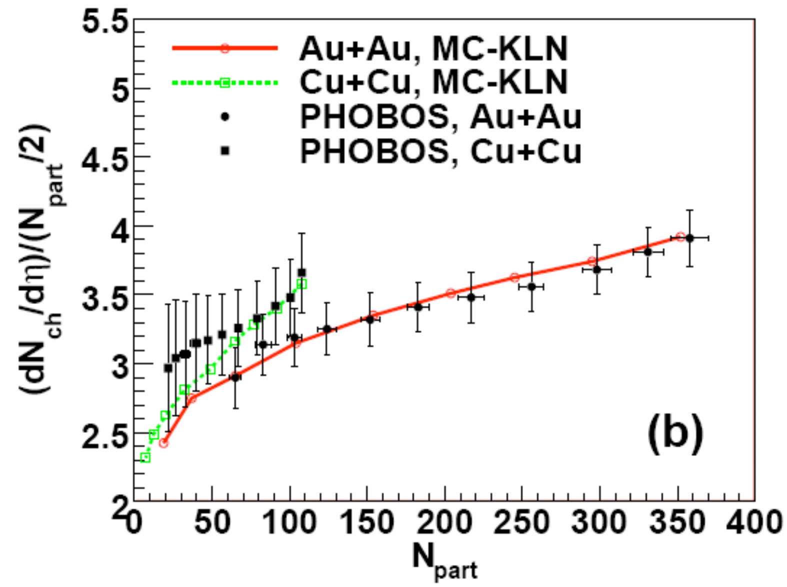
What's this?

Next run (2010): Novel HBD (hadron blind Cerenkov detector) to reject $e^{\pm}$ background



A Known Unknown – initial eccentricity





$$\sigma_{xy} = \overline{xy} - \bar{x}\bar{y}$$

$$\epsilon_{std} = \frac{< y^2 > - < x^2 >}{< y^2 > + < x^2 >}$$

$$\sigma_y^2 =< y^2 > - < y >^2,$$

$$\epsilon_{rp} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$

$$\sigma_x^2 =< x^2 > - < x >^2$$

$$\epsilon_{part} = \frac{\sigma_y'^2 - \sigma_x'^2}{\sigma_y'^2 + \sigma_x'^2} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}.$$

$$\varepsilon_4 = 1 - \frac{8\sigma_{xy}^2}{\sigma_x^4 + \sigma_y^4 + 2\sigma_{xy}^2},$$

- ***Geometric fluctuations are very important – be skeptical of any claim that does not include them***
- ***eccentricity should be constrained***

Roy A. Lacey, Stony Brook University; CATHIE-TECHQM Workshop, BNL USA, Dec 14-18th, 2009